THE HISTORY OF VERTEBRAL SCREW AND PEDICLE SCREW FIXATION

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INTRODUCTION

The indications to perform a lumbosacral fusion and the subsequent clinical outcomes are topics of debate. There are a multitude of factors that affect outcome. The use of instrumentation to reduce the need for postoperative external immobilization and bed rest through immediate stabilization of the spine is attractive. The use of instrumentation also may improve the fusion rate.

Since the 1940's, vertebral screw and pedicle screw fixation have evolved and become increasingly popular among spine surgeons. Both methods are designed to provide immediate stability and rigid immobilization of the spine without sacrificing additional motion segments required by other forms of conventional instrumentation (e.g. Harrington, Luque). Pedicle screw fixation has the additional benefit of generally not requiring the presence of intact laminae, facet joints, or spinous processes.

VERTEBRAL SCREW FIXATION

The history of vertebral screw fixation dates back to 1944. King first described the placement of screws (three-quarters of an inch for women; one inch for men) parallel to the inferior border of the lamina and perpendicular to the facet joints of lumbar vertebrae in an attempt to avoid postoperative external immobilization and prolonged bed rest (Figure 1).[26,27] However, patients were encouraged to stay in bed for three weeks following surgery. A pseudarthrosis rate of approximately 10% was reported in patients fixed with screws and grafted from L5-S1. One (2.3%) patient experienced "nerve-root irritation" as a result of a poorly positioned screw which was subsequently removed.

In 1949, Thompson and Ralston reported a pseudarthrosis rate of 55.1% using a similar technique in 49 patients undergoing L4-S1 instrumentation and grafting.[59] Results were better (12.2% pseudarthrosis rate) in 41 additional patients instrumented and grafted from L5-S1. Patients were allowed out of bed two to three weeks following surgery, and no external support was used. Bosworth (1957) also related poor results and stated that screw fixation did not prove to be of value compared to the difficulties encountered in screw placement.[4]

Boucher in 1959, and Pennel in 1964 described a method of internal fixation using longer (one and a half to two inches), machined, stainless steel screws placed through the fact joints (Figure 2).[5,43] Screws placed at L5-S1 more closely approximated the longitudinal axis of

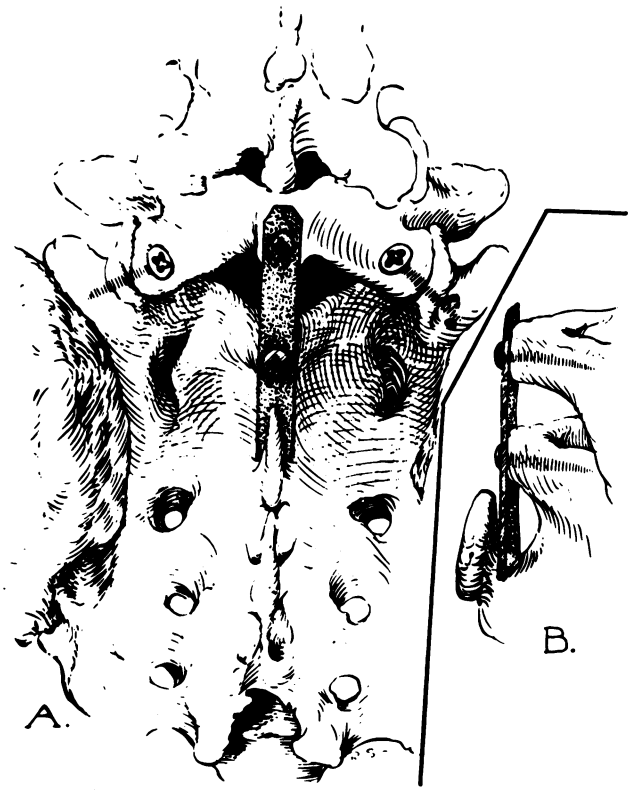

Figure 1
Metal screws placed through the lateral articulations as first described by King. When the spinous processes were well developed, a tibial graft was fastened with small screws. (Reproduced with permission from King, D.: Internal fixation for lumbosacral fusion. J. Bone Joint Surg. 30-A:560-565, 1948).

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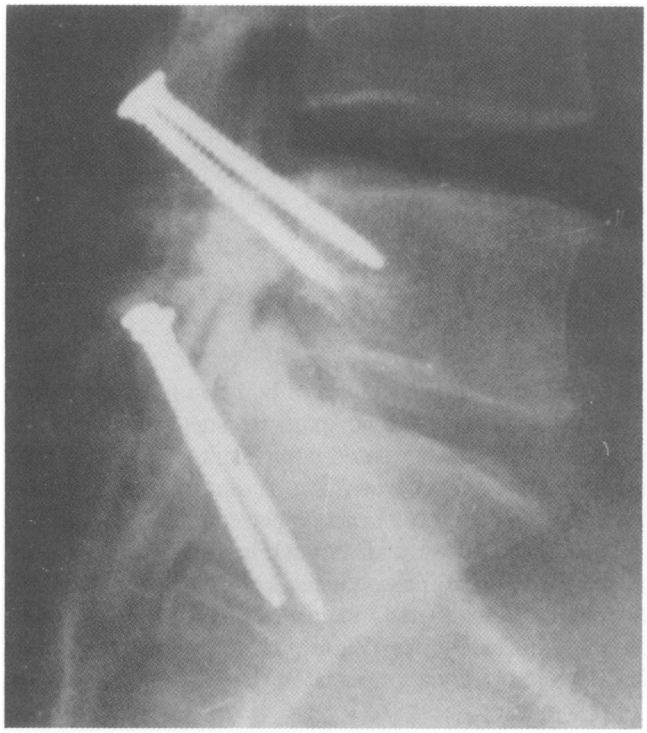

Figure 2
Boucher was the first to describe the placement of screws through the pedicle. Screws were placed obliquely through the lamina and facet joint into the pedicle and vertebral body (or sacral ala). (Reproduced with permission from Boucher, H.H.: A method of spinal fixation. J. Bone Joint Surg. 41-B:248-259, 1959).

the body, nearly transversing the full A/P diameter of the sacrum. Screws were typically placed through the inferior facet and into the pedicle and vertebral body below. Boucher recognized that screws placed through the pedicle improved fixation. There were no hardware failures in 160 patients undergoing single level fusions. There were two broken screws in 14 patients undergoing multilevel fusions. Root irritation from poorly positioned screws occurred in two (1.1%) patients. Four of the forty-nine (8.2%) patients with spondylolisthesis developed pseudarthroses.

In 1970, Buck first described the use of screw fixation in the direct repair of isthmic-lytic defects in 16 patients with spondylolisthesis.[6] Fully threaded screws were placed at the inferior edge of the lamina, through the par interarticularis, and into the pedicle and vertebral body. Screws were partially withdrawn for autogenous grafting, and then fully advanced. One patient's fusion failed as both screws loosened and the lamina became unstable. Gaps measuring over 4mm were felt to be "beyond the practical limit of repair".

Later, Evans (1977) reviewed 190 patients instrumented with screws using Boucher's technique.[14] Like previous reports, failure was greatest at the L4-5 level (33% for

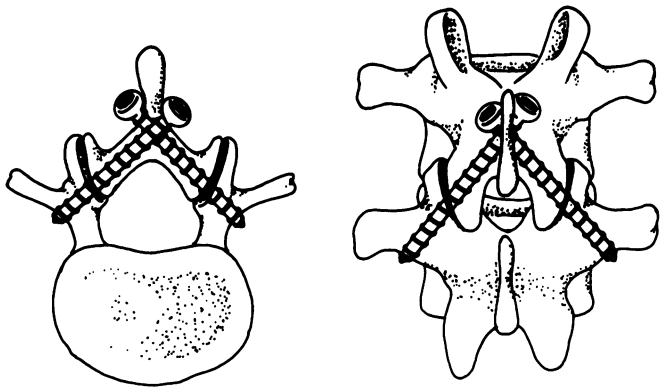

Figure 3
Translaminar facet joint screws were first used by Magerl to supplement external pedicular fixation. Screws were placed through the entire lamina, perpendicular to the facet joint, ending at the base of the transverse process. (Reproduced with permission from Jacobs, R.R., Montesano, P.X., and Jackson, R.P.: Enhancement of lumbar spine fusion by use of the translaminar facet joint screws. Spine 14:12-15, 1989).

single level L4-L5 fusions). They reported a 15% failure rate at the L5-S1 level.

In contrast, Andrew (1985), in a retrospective review, found no difference in outcome between single level L4-5, L5-S1, or two level fusions using this technique.[3] In his study, fifty-nine patients were followed an average of nine years. One-and-a-quarter-inch screws were used with a posterior corticocancellous graft. He noted no broken or loose screws, and, with the exception of one patient, all fusions "appeared" solid. Four screws were "malpositioned", giving rise to "sciatica". Ninety seven percent of patients returned to their previous occupation within six months.

Jacobs (1989) likewise reported good results using translaminar facet joint screws (Figure 3) with an autologous posterolateral graft.[22] Using the technique previously described by Magerl,[39] he reported 93% clinical improvement and 91% solid fusion in 88 consecutive patients followed prospectively an average of 16 months. AO/ASIF 4.5-mm cortical screws of approximately 50 mm were placed at the base of the spinous process, through the lamina, across the facet, ending at the attachment of the transverse process to the pedicle. Seventy millimeter screws inserted into the sacral ala were used at the lumbosacral junction.

These more recent reviews reported improved results compared to earlier studies. This difference may reflect better surgical technique, improved instrumentation and/or indications. Nevertheless, the overall results of vertebral screw placement were mixed. High fusion rates reported at the L5-S1 level were not unlike that seen in uninstrumented patients. Complications including infection, nerve damage, facet fracture, screw loosening and breakage were minimal.

PEDICLE SCREW FIXATION

In 1970, Roy-Camille, guided by Judet, first described the use of posterior plates with screws positioned sagittally through the pedicles and articular processes (Figure 4).[45-49] He began using this pedicle screw plate system in 1963. The plates were designed following anatomical studies that demonstrated the average interpedicular distance in the lumbar spine to be approximately 2.6 centimeters. Collar reinforced holes were thus spaced 1.3 centimeters apart to allow for the placement of 4.5 mm screws within the pedicle. Adjacent, smaller screws were placed into the facet joint to augment fixation when needed. Special plates were designed for short fusions and lumbosacral fusions. Two screws could be placed through one central hole within the plate and into the pedicle for improved purchase. His system was applied to a number of spinal disorders and his results were encouraging. He reported nearly 100% success rate in lumbosacral fusions. His instrumentation was capable of partially reducing slips in high grade spondylolisthesis. This work set the foundation for pedicle screw instrumentation.

Cabot described a midline lumbosacral plate that was hooked onto the spinous processes and also fixed with transpedicular screws.[7] Louis and Maresca subsequently modified Roy-Camille's technique and instrumentation.[33,34] Louis later reviewed 455 cases of his modified screw-plate fixation followed an average of 31.6 months. Solid fusions occurred in 97.4% of his single-staged posterior approaches, and 100% of combined approaches. However, his criteria used to establish this high fusion rate is questionable. He stated "since dynamic roentgenograms failed to demonstrate instability..., the diagnosis of nonunion was considered probable in those patients whose persistent lumbar spine pain subsided immediately after they began wearing plaster corset braces."

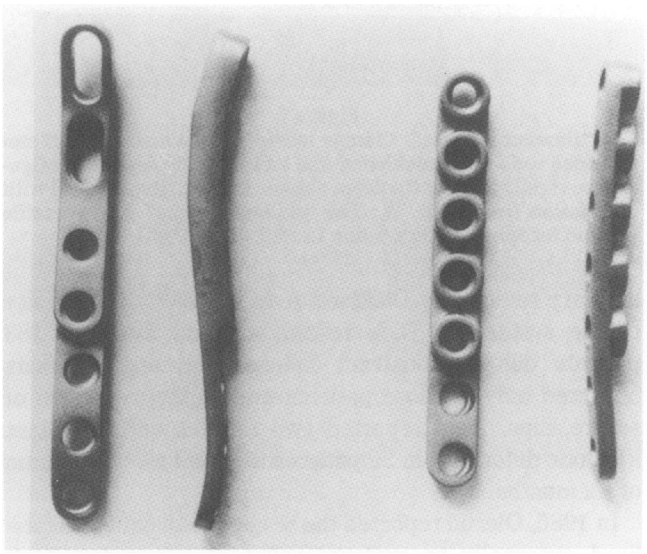

Figure 4
Segmental pedicle screw plate fixation was pioneered by Roy-Camille. His plates were made of cobalt-chromium alloy or stainless steel and contained collar reinforced holes placed 1.3 centimeters apart. Special plates were designed for the reduction and fixation of spondylolisthesis (left), in addition to lumbosacral fusions (right) where the inferior holes were flat and oblique for screws placed beneath the skin into the sacral ala. Plates ranged from 49 to 190 mm in length with 5 to 15 holes. (Reproduced with permission from Roy-Camille, R., Saillant, G., and Mazel, C.: Internal fixation of the lumbar spine with pedicle screw plating. Clin. Orthop. Rel. Res. 203:7-17, 1986.)

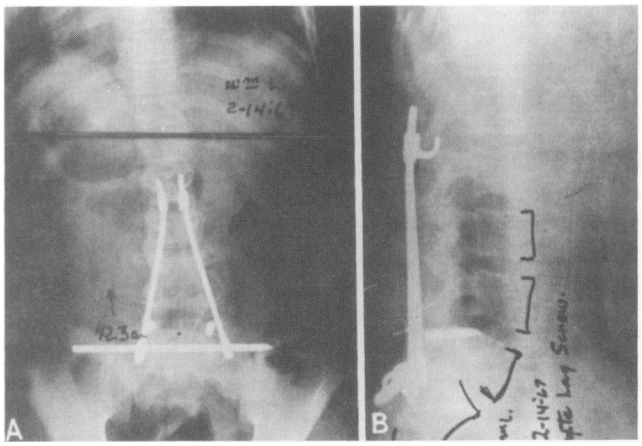

Figure 5
The first reported case of transpedicular screw placement in the United States. (Reproduced with permission from Harrington, P.R., and Tullos, H.S.: Reduction of severe spondylolisthesis in children. South. Med. J. 62:1-7, 1969.)

Transpedicular screws quickly were modified to be used in several other situations. Harrington and Dickson, Sijbrandij, and others, have inserted screws into pedicles and vertebral bodies along with modified Harrington instrumentation for the reduction and fixation of spondylolisthesis, as well as in the management of unstable lumbar fractures.[11,12,18,51,62]

Harrington and Tullos are among the first authors in the United States to describe transpedicular screw fixation (Figure 5).[19] In 1967, two children with progressive, symptomatic spondylolisthesis were reduced and instrumented with a Harrington A-frame supplemented with L5 pedicle screws. "Lag screws" placed through the pedicles of L5 were wired to the Harrington distraction rods to aid in the reduction of the slip.

External transpedicular fixation of the lower thoracic and lumbar spine was originally developed by Magerl in 1977 (Figure 6).[38,64] His system ("fixateur externe") consisted of two pairs of long Schantz screws and an adjustable external fixation device. Screws were placed by either open or closed technique. The fixation device, consisting of two transverse bars and three threaded rods with triangular locking plates, provided rigid stability. The system could be applied in distraction, compression, or in a neutral mode. Magerl found the stability of the system was

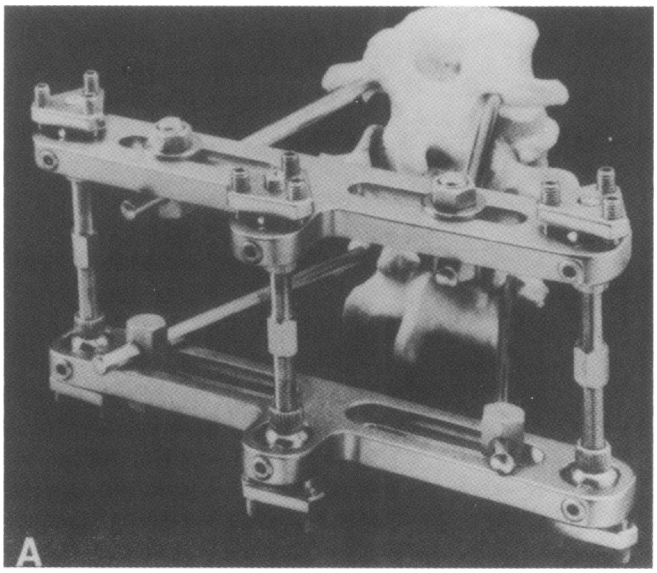

Figure 6
External spinal skeletal fixation ("fixateur externe") was originally developed by Magerl using Schanz screws fixed by gliding connectors to a transverse bar and rod linkage system. Three dimensional fixation was controlled through ball-socket joints located at the intersections of the threaded rods and bars. Triangular locking plates secured the desired position. (Reproduced with permissions from Magerl, F.P.: Stabilization of the lower thoracic and lumbar spine with external skeletal fixation. Clin. Orthop. Rel. Res. 189:125-141, 1984).

enhanced by preloading the Schanz screws in distraction and by adding translaminar screws through the facet joints. In 1984, Magerl reviewed 52 patients (42 acute spinal trauma; 8 osteomyelitis, 2 decompression) followed for a minimum of one year.[39] There were no deep infections, and all superficial screw tract irritation resolved with the screws in place, or upon removal. Loosening of the screws prompted one patient to undergo premature removal of the device. Optimal results, without loss of reduction, were obtained when the device was kept in place an average of 18-19 weeks. In most cases, the damaged intervertebral discs collapsed following removal of the fixator, despite concomitant facet screw fixation and fusion. Although results with this system were encouraging, Magerl did not recommend its use for common degenerative spinal disorders.

Following Magerl's initial description of external four-point fixation with Schantz screws, Dick developed a similar internal device, which he called the "fixaturer interne" (Figure 7).[10] This system also utilized 5 mm Schantz screws to create long lever arms to facilitate manual reduction. The screws were connected to the 7 mm threaded longitudinal rods by clamps which were mobile in all directions allowing compression, distraction, kyphosis, lordosis, and rotation. Biomechanical testing with anterior bending moments demonstrated its increased rigidity in comparison to Magerl's external fixator. Preliminary reviews by Dick and Aebi revealed the diversity of the system.[1,2,9] Dick re-instrumented 3 of the 183 patients due to construct failure. Neurologic deficits occurred only in those patients undergoing reduction of severe slips. Aebi reported two failures with resultant kyphotic deformity in 30 patients followed for a minimum of six months.

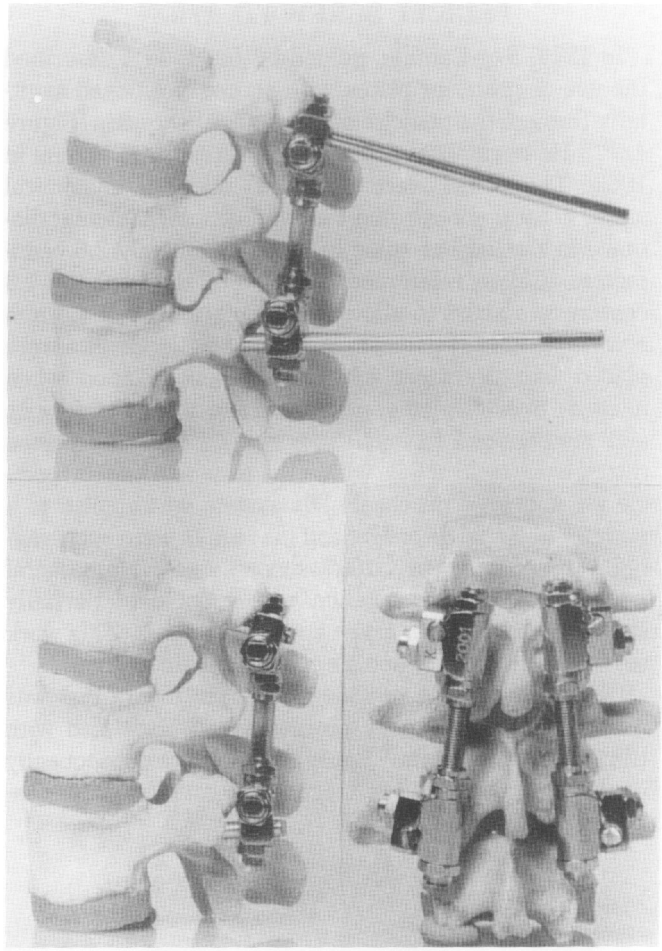

Figure 7
The "fixateur interne". Clamps located at the ends of the 7mm threaded rods were positioned and locked in the desired configuration, rigidly holding the 5mm Schanz screws. (Reproduced with permission from Dick, W.: The "fixator interne" as a versatile implant for spine surgery. Spine 12:882-900, 1987.)

In 1986, Olerud reported the results of 18 patients stabilized externally to evaluate relief of severe low back pain.[41] Transpedicular Schantz screws attached to a modified Hoffman fixator was used. Sixteen (89%) were reported to have experienced dramatic improvement. He suggested that this device could be used as definitive treatment for spinal instability or as a clinical trial to determine level(s) of fusion. This device could also be used to determine the stability of previous fusions. Eight patients who presented with painful fusions responded with marked relief when stabilized. Three were not con-

sidered radiographically healed. This indicated to Olerud that despite an acceptable radiographic appearance, either the fusion was not healed, or the stability of the fusion was insufficient to prevent painful movements between segments. Olsson, using roentgenstereophotogrammetric techniques, demonstrated significant movement between levels despite bilateral osseous union in posterolateral fusions.[42]

Following the original work of Roy-Camille, et al., and the modifications of Louis et al., several other designs of transpedicular screw-plate fixation have arisen.

Use of an AO tibial dynamic compression plate within the spine was initially described by Müller in 1979, and later reviewed by Thalgot (Figure 8).[40,58] Like previously designed systems, the screw-plate interface was not rigid, and micromotion was allowed to occur. The AO DCP plate has long, oval shaped holes which provides greater angular freedom for placement of the 6.5 mm, fully threaded cancellous screws. Forty-six patients followed for 12-30 months were studied. Asymptomatic screw loosening occurred in nearly 11% of patients, and 6.5% had broken screws. Nerve root irritation requiring screw removal occurred in 6.5% of patients. Seventy-two percent were reported to have solid fusions. The use of a modified AO plate, the "notched plate", has also been described.

In 1982, Steffee developed a segmental spinal plate and pedicle screw system that could be used from the lower thoracic spine to the sacrum (Figure 9).[53-57] After originally using standard AO neutralization plates with fixed holes, Steffee developed a slotted plate with "nests" in the slots, permitting easier multilevel insertion and positioning of modified cancellous screws. He too recognized the importance of the contouring the plates to reflect the physiological curves of the spine. He also stressed the importance of using the largest single screw suitable for each pedicle.

Steffee stated in his initial publication that his mean follow-up was too short to provide a meaningful retrospective review. He reported 90 percent good to excellent functional and clinical ratings. Complications in a preliminary follow-up of 120 patients included seven deep wound infections, two radiculopathies secondary to graft placement, eight hardware failures, and five cases of pseudarthrosis with subsequent hardware removal. The incidence of hardware failure decreased following ongoing modifications in the instrumentation.

Subsequently, West, Whitecloud, and Zuchermann have retrospectively examined their experience with the VSP (Variable Screw Placement; Steffee) system.[60,61,63,65] Since each applied the instrumentation in treatment of a number of different problems, clinical results were mixed and difficult to assess. The presence of postoperative pseudarthrosis ranged from 11% to 18%. West reported

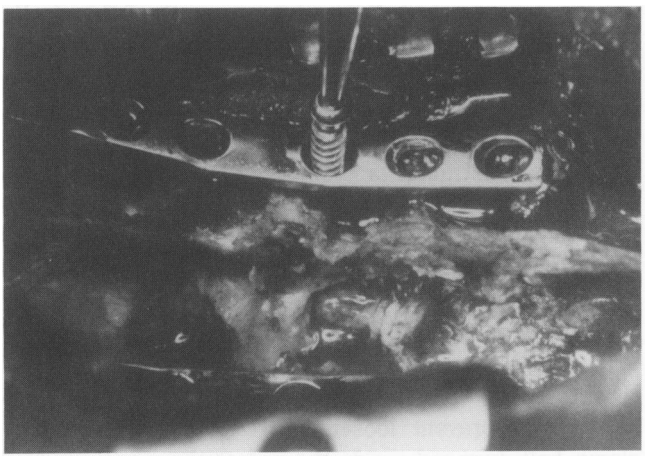

Figure 8
The AO DCP plate is not rigid at the screw-plate interface, and thus requires the presence of an intact anterior spinal column for maintenance of stability. The plate is contoured to the spine, and 6.5 mm fully threaded cancellous screws are used. (Reproduced with permission from Thalgott, J.S., LaRocca, H., Aebi, et al.: Reconstruction of the lumbar spine using AO DCP plate internal fixation. Spine 14:91-95, 1989.)

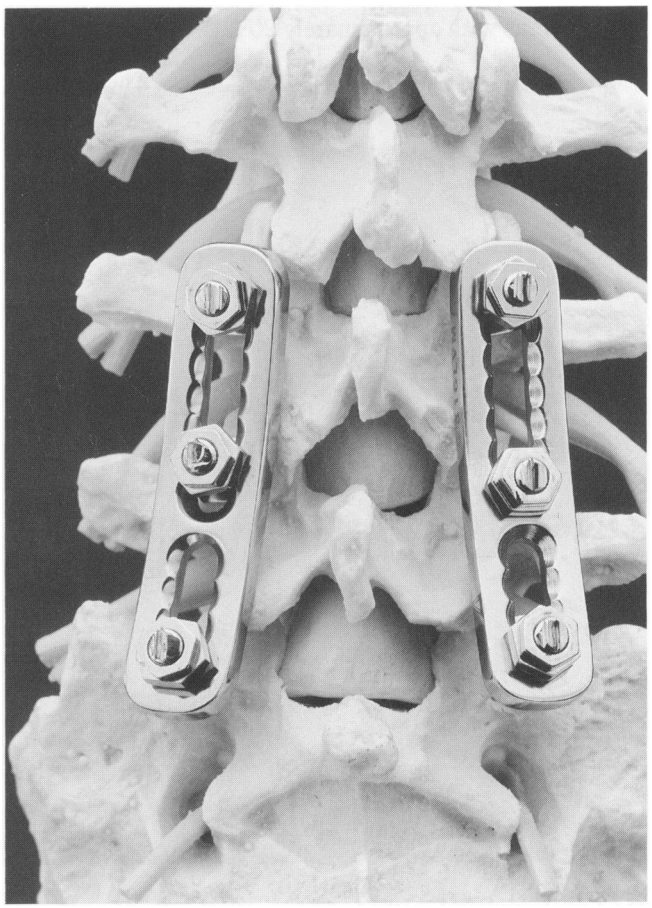

Figure 9
The Variable Screw Placement (Steffee) system. (Reproduced with permission from the AcroMed corporation).

that this rate was highest in those patients who had previous pseudarthroses (38 percent). All patients who developed a pseudarthrosis were labeled clinical failures, either by self-assessment or the requirement for further surgery. The failure rate was 21% for the spondylolisthesis group, 20% for the degenerative group, and 48% for the pseudarthrosis repair group. Deep and superficial wound infections within the three studies occurred seldomly (0-5%), and were not statistically different from reports of non-instrumented fusions.

In 1986, Eduardo Luque introduced another method of interpeduncular segmental fixation using pedicle screws wired to Luque rods.[35] A preliminary review of 20 cases followed an average of 14 months demonstrated continued anatomic "correction of pathology" in 80% of patients. In 1988, Luque further introduced a new, "semirigid", cannulated screw and slotted plate system (Figure 10).[37] He stressed the system's function as a posterior tension band, and that load sharing by the anterior column was necessary for maintenance of stability. Thus, all patients instrumented for the treatment of fractures were immobilized in plaster jackets for three months or until the fracture and fusion were solid. Eighty cases were followed an average of 18 months with approximately 20% losing anatomic correction. No evaluations of pseudarthrosis formation were made in either study. Luque's most recent review in 1990 evaluated 57 cases of instability instrumented with the "semirigid" screw and plate system.[36] With an average follow-up of 2.6 years, he reported one loose screw, one broken screw, and 2 (3.5%) pseudarthroses. The majority of patients experienced improvement in pain.

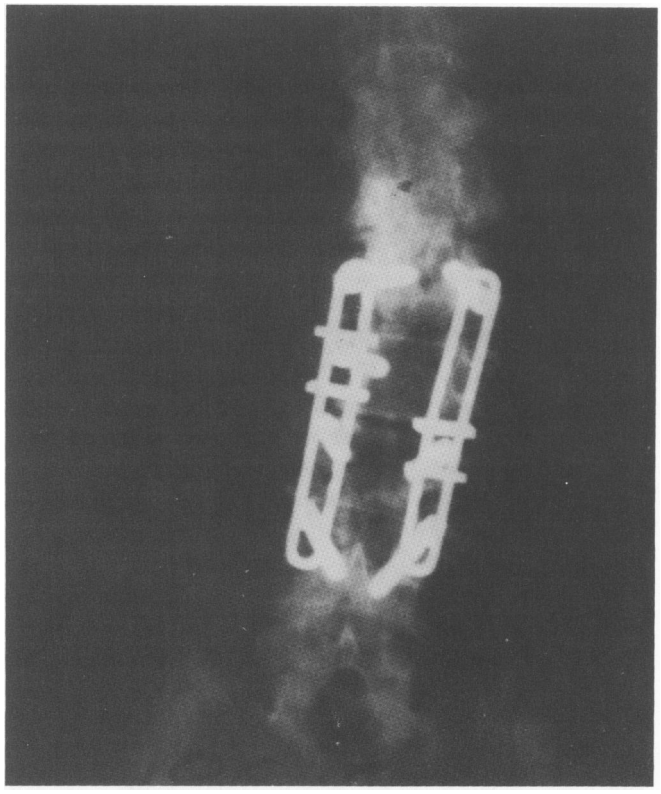

Figure 10
The Luque semirigid method of interpedicular fixation. (Reproduced with permission from Luque, E.R., Rapp, G.F.: A new semirigid method for interpedicular fixation of the spine. Orthopaedics 11:1445-1450, 1988.)

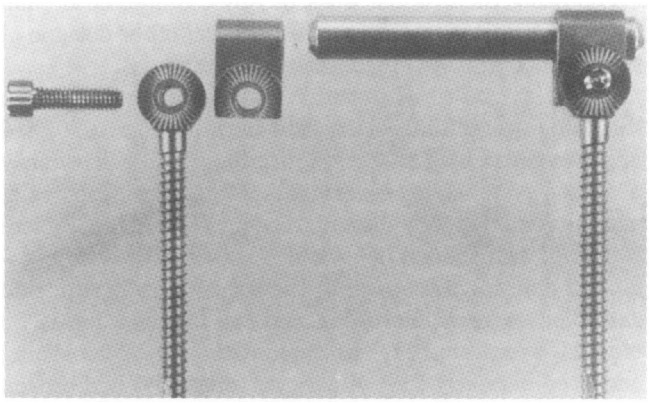

Figure 11
The Vermont Spinal Fixator. (Reproduced with permission from Krag, M.H., Beynnon, B.D., Pope, M.H., et al.: An internal fixator for posterior application to short segments of the thoracic, lumbar, or lumbosacral spine: Design and testing. Clin. Orthop. Rel. Res. 203:75-98, 1986.)

Following extensive biomechanical testing, Krag designed a pedicular screw-rod system called the Vermont Spinal Fixator (VSF) (Figure 11).[28,30] He argued that interpedicular screw fixation was superior to standard Harrington or Luque fixation for the following reasons: 1) They were designed for "short segment" spinal defects, spanning only 2-3 vertebrae, not the 5-7 typically needed by Harrington rods to achieve adequate stabilization. 2) 3-dimensional, 3 column fixation was achieved by controlling flexion, extension, and rotational movements. Thus, the screw-plate (or rod) system functioned as a fixator, not as a distracter or compressor. (It is our opinion, as well as others, that rigid fixation with pedicle screw systems can only be achieved in the presence of a stable anterior column.) 3) It readily allowed fracture or spondylolisthesis reduction without violation of the spinal canal with hooks or wires. The VSF system, consisting of screws, articulating clamps, bolts, and connecting rods, provides rigid fixation while allowing for three dimensional adjustability. To prevent loosening, the threads which the clamp bolt engaged inside the rod clamp are made in a special pattern known as Spiralock®. Additional advantages of this design include its ability to be repeatedly tightened, loosened, and retightened without degradation, improved load distribution, and lack of a separate locking nut. A preliminary review of the first 46 consecutive patients treated with this instrumentation revealed three

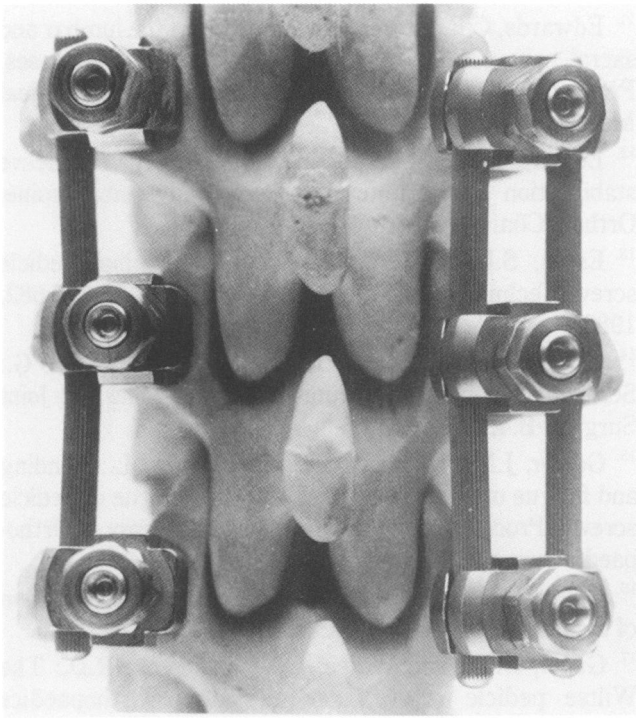

Figure 12
The Wiltse pedicle screw fixation system. (Reproduced with permission from Guyer, D.W., and Wiltse, L.L.: Pedicle screw fixation of the lumbar spine. Surg. R. for Orthop. 2:17-21, 1989.)

broken screws and one loose screw. Follow-up was too short to adequately assess fusion outcome.

The Wiltse pedicle screw system was yet another system introduced in the 1980's (Figure 12).[16,17,21] This system consisted of pedicle screws connected to stainless steel rods by saddle clamps. The use of rods (over plates) increased the adaptability of the system to irregularly contoured spines. This was a potential advantage over other systems less tolerant of changes in pedicle direction. Steffee has argued that the VSP system can be applied to deformed spines through the use of "working plates", where meticulous adjustments of alignment are made at each spinal segment. The Wiltse pedicle system, the AO "fixator interne", and the Vermont Spinal Fixator offer greater flexibility in screw direction.

Since the saddle clamps of the Wiltse system are small in size, they can usually be placed with minimal disturbance of the facet joint. One or two rods can be used on each side. The one rod system offers the advantage of saving time and the possibility of not further damaging the facet at the upper end of the fusion. Nevertheless, Guyger does not recommend unilateral rod placement.[17]

In 1989, Horowitch reviewed 99 patients instrumented with the Wiltse system.[21] Follow-up averaged 20 months. Hardware failure was seen in in 7% of patients. Screw breakage was seen in 5% of patients, rod breakage in 2%, clamp loosening in 1%, and screw loosening in 3%. Radiographs demonstrated the presence of union in 68% of patients. Overall, 70% stated that they received some benefit from surgery.

Other forms of posterior instrumentation that utilize pedicular screws include the Cotrel-Dubouset system, the ISOLA® Spinal System, the Jacobs pelvic fixator, the Texas Scottish Rite system, and Zielke instrumentation.[8,23,44,52]

THE PEDICLE SCREW

The design of the pedicle screw continues to be modified and updated for improved strength and purchase (Figure 13). Screws with wider cores are generally stronger and less likely to break. The stress placed upon

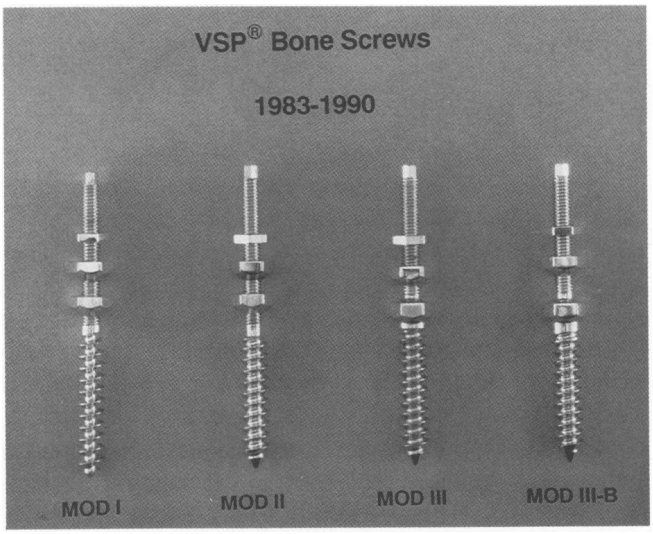

Figure 13
Evolutionary design changes in the VSP (Steffee) screw. (Reproduced with permission from the AcroMed corporation.)

the screws are greatest at or near the screw-plate (or rod) interface. It is this location that the hardware most often fails. This occurs through loosening of the screw-plate (or rod) interface, or through screw breakage. Thus, as screw designs have evolved, the core and platform (base-nut) diameters have increased to withstand these higher stresses. The most recent design modification of the VSP (Steffee) system features an integral fixed lower nut that is machined from the same bar stock and thus is stronger and more resistant to breakage. Also, various washers and articulating clamps are now available which allow for a concentric (flush) fit between the screw and plate. This allows loads to be more evenly transmitted between the screws and the linking device. Screw pull-out is relatively uncommon, except in the osteoporotic spine, and following multiple level fusions where large lever arm forces arise. Generally, the threaded portion of most pedicle screws have a larger thread diameter, small core diameter, and a greater pitch for improved purchase.

CONCLUSION

The field of vertebral screw and pedicle screw fixation has grown immensely following King's and Roy-Camille's initial descriptions. New systems and techniques are continuously becoming available, and old systems are being modified and up-dated.[25,44,52] Long term follow-up studies, in addition to randomized prospective studies, are needed to appropriately evaluate the efficacy of these systems. As our knowledge and experience grows, we will be able to better determine the limitations, indications, and usefulness of these systems.

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